fifth and sixth dorsal arches were then removed and the dura incised in an upward direction. It was then seen that the right posterior spinal vein ran a normal course, while the left was much enlarged and ran together with the eighth left posterior root through the opening in the dura. The vein was almost again as large as the nerve root. (See Fig. 2.) The vessel was ligated at the dural opening and about 2 cm. of it was excised. The wound was closed in the usual manner.

Convalescence was uncomplicated. The patient was out of bed in two and a half weeks; the symptoms of spinal disease grew less and less distinct; by the beginning of November all of the sensory and most of the motor symptoms had disappeared. Three months after the operation he was entirely well, and he was well when last heard from about six months after the operation.

It may be that this remarkable result was due to the decompressive effect of the laminectomy. Pearce Bailey and I have shown that the free opening of the spinal canal and the entrance of air into the subdural space has a striking influence upon the spinal cord, and may, and often does, affect some change which temporarily or permanently benefits or checks the symptoms of local spinal disease. This may be the explanation for the postoperative course in several of our patients.

THE ROLE OF THE SYMPATHETIC SYSTEM IN THE DIAGNOSIS OF ABDOMINAL DISEASES.

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When we see a patient with the following classical history: sudden epigastric or umbilical pain—followed by vomiting—later the pain becoming localized in the right lower quadrant of the abdomen, the right rectus muscle becoming rigid over the painful area, then we palpate, find tenderness at or about McBurney's point, make the diagnosis of appendicitis and commonly conclude that the tenderness experienced is due to pressure by the finger on the diseased organ. If, however, we operate, the appendix is very often found not under the point where pressure was exerted, but some varying distance therefrom. Similarly in disease of the gall-bladder, pressure exerted over the organ causes pain, which pain is increased when the gall-bladder is made to descend by deep inspiration. If the diseased gall-bladder is exposed it may be handled in various ways without giving rise to the sensation pain.

It is tempting and may be profitable to hunt for some reasonable explanation of the sequence of symptoms in such a disease as

appendicitis, where so many of the symptoms seem unconnected with the organ at fault, and also to endeavor to find some explanation why a chronic appendicitis may give rise to symptoms which must be attributed by the clinician to gastric ulcer which is found to be non-existent on exposure of the stomach.

The convenient expression "reflex pain," is too often used as a cloak to cover our ignorance, and often when using it we forget, if we ever knew, what constitutes a reflex pain.

Originally the gastro-intestinal canal was a straight tube developed in the dorsal region and pushed into the primitive body cavity in such a fashion that it became enveloped with peritoneum but retained its connection with the dorsal structures by means of bloodvessels and of nerves which lay between the layers of the primitive mesentery. From the original straight tube there developed the liver, pancreas and spleen near the dilated portion of the tube which came to be the stomach. As development proceeded the various organs assumed the positions in which they are found in the normal individual. Thus we see that the vascular and the nerve supply of each and every part of the digestive tract was arranged as if these viscera were to retain a position in the middle line. The viscera ultimately normally take up positions which may be remote from the middle line, yet their telephone supply remains the same except for the necessary elongation of the wires. This may explain why the early pain of most visceral lesions is generally median.

What is the nerve supply of the gastro-intestinal tract? The nerves of the abdominal viscera pass to a very large extent into the solar or celiac plexus, which is a congeries of nerve filaments and ganglia (special ganglia in it are the right and left semilunars). The solar plexus is connected above with the aortic plexus of the thorax and below with the abdominal aortic plexus, etc. By the splanchnic nerves it communicates with the gangliated sympathetic cord and so with the anterior primary divisions of the spinal nerves. The plexus is connected with the cranial nerves through the pneumogastric route. The left vagus, distributed to the anterior surface of the stomach, only anastomoses with a branch from the left semilunar ganglion in about 25 per cent. of cases. This anastomosis recalls to a certain degree the loop of Wrisberg, formed by the union of the right vagus and great splanchnic nerves. The anterior gastric plexus may sometimes anastomose with the sympathetic surrounding the left diaphragmatic artery (Poirier and Charpey). The right vagus, after giving some branches to the esophagus, enters into the right semilunar ganglion, where it loses its anatomical identity. While the vagus has no connections with the cephalic sympathetic it gives the most important parts of its fibers to the ganglia on the visceral branches of the sympathetic (Wrisberg's, intracardiac and semilunar ganglia). These ganglia are the true nodal

points of junction between the pneumogastric and sympathetic systems, beyond which the nerves are anatomically inseparable.

Another connection of the plexus must be considered, viz., that with the phrenic nerves. The anatomy of the phrenics themselves is important from a clinical standpoint.

The principal fibers of the phrenic nerves come from the fourth cervical, but the third and fifth cervical nerves provide secondary roots. In the thorax the phrenic sends branches to the pleura, pericardium and diaphragm. Most of the pericardial branches come from the right nerve. This is important as explaining how pain in the *right* shoulder arises through impulses transmitted through the supra-acromial branch of the fourth cervical nerve.

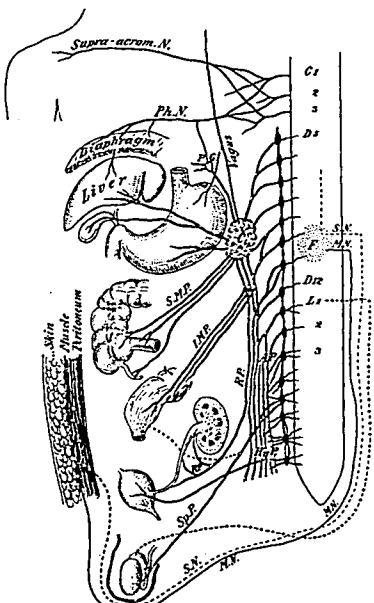
The right phrenic besides innervating the diaphragm sends fibers to the liver and to the anterior parietal peritoneum as low as the umbilicus. Luschka thinks the peri-umbilical pain in peritonitis is due to excitation of these last-mentioned fibers.

Another branch of the right phrenic, uniting with the phrenic ganglion and fibers of the sympathetic, helps to form the diaphragmatic plexus, which also receives branches from the five lowest intercostal nerves. The left phrenic has no connection with the phrenic ganglion but sends a few twigs to the left semilunar and solar ganglia. Probably irritation of the right phrenic nerve is the explanation of the anomalous symptoms found in a woman, aged twenty-one years, who came to me complaining of severe pain in the right abdomen. From childhood she had been troubled with nausea and vomiting, without pain, coming on from a few minutes to an hour after meals. Sour eructations were occasionally present. Hunger distress at night or in the early morning was frequently noticed. In recent years and when seen she frequently suffered from a feeling as if the liver were a heavy weight pressing on her right side when she lay on that side and dragging on the right side when she lay on her left side. Three weeks before I saw her there was an attack of severe abdominal pain in the hepatic region accompanied by fever of 102°, slight jaundice, and clay stools. Three days before admission to hospital pain in the hepatic region returned, there was a slight chill and a temperature of 103°. There was a slight hacking cough without sputum. The pain was all over the hepatic area and extended to the angle of the right scapula. There was exquisite tenderness over the region of the gall-bladder and appendix. The right chest gave the ordinary signs of empyema. Thoracotomy was followed by complete disappearance (temporary at least) of all the abdominal symptoms.

Every surgeon remembers how routine examination of the chest has saved him from operating for intestinal obstruction when pneumonia was the cause of the menacing symptoms.

The stimuli from the disease, in such cases, seem to affect the phrenic or lower intercostal nerves, giving rise to abdominal pain, rigidity, etc., to such a degree as to be most deceiving. The accom-

panying diagram shows roughly the connections of the solar, superior and inferior mesenteric and the spermatic plexuses. The apparent functions of the visceral nerves are (1) to transmit afferent stimuli to certain centers from which (2) efferent impulses are sent to the viscera. The efferent impulses stimulate or inhibit peristalsis, secretion, etc., in the organs in response to the needs of the body as communicated by means of the afferent impulses. The nerve



Ph. N., phrenic nerve; *P. G.*, phrenic ganglion; *C.*, celiac or solar plexus; *S. M. P.*, superior mesenteric plexus; *I. M. P.*, inferior mesenteric plexus; *R. P.*, renal plexus; *A. P.*, aortic plexus; *Hy. P.*, hypogastric plexus; *Sp. P.*, spermatic plexus; *C.*, 1-2, cervical nerve roots; *D.*, 1-2, dorsal nerve roots; *S. N.*, sensory nerve; *M. N.*, motor nerve; *F.*, area of stimulation in cord.

centers in question carry on these functions without the cognizance of the higher brain centers.

If, however, owing to local conditions, *e. g.*, inflammation or any irritation, there is sudden and great increase in the number of stimuli passing up from any viscus then the nerve center is incapable of

handling the increased volume of material, and there is radiation of the impulses in all directions.

According to Mackenzie, who has written much on this subject, the radiating impulses stimulate or affect neighboring nerve centers or tracts. These nerve tracts may be the trunks of sensory nerves passing up the spinal cord from distant parts and the stimuli applied in their course pass up to their cerebral centers and are translated into terms of pain, but the pain is thought to come from the end of the nerve and not from the point in which the stimuli actually originated. This is a referred pain.

In the same way the radiating stimuli may affect a motor path—pass down to the muscles supplied by the path and cause contraction or rigidity of these muscles.

Let us take a concrete clinical example. In appendicitis an abnormal volume of stimuli passes from the appendix through the superior mesenteric to the preaortic plexuses, reaches the spinal cord and there radiates. If a sensory nerve or nerve cell is irritated by the radiating impulses pain is experienced and is located in the territory of distribution of that nerve; in the case of the appendix this is near McBurney's point.

Head expresses the same notion as follows: "When a painful stimulus is applied to a part of low sensibility in close central connection with a part of much greater sensibility, the pain produced is felt in the part of higher sensibility rather than in the part of lower sensibility to which the stimulus was actually applied." In the same way "when from any cause one or other of the cutaneous senses is depressed in a given area stimulation in this region may give sensations which are referred to the symmetrical area on the other side of the body, or if this also is involved, it may be referred to the area next above or below in the spinal order." (Howell.) To this peculiarity the name of allochiria has been applied.

Stimuli from the appendix center constantly acting on the sensory nerve or its receptors, keep it in a constant state of irritation, so that if its distal terminals are stimulated, *c. g.*, by palpation, etc., there is distinct tenderness experienced. Such irritability of nerve cells gives rise to the hyperalgesic zones of Head and McKenzie.

Head and Rivers have shown that in the skin there are two systems of sensory fibers, viz., the protopathic and epicritic. Protopathic sensibility responds to extremes of heat and cold, to pain, to pressure, etc.

Another set of nerves (system of deep sensibility) conveys sensations of deep pressure and pain, localizes pressure, and tells of alterations in the position of joints, muscles and tendons. It may be described as a rough index of sensation. Epicritic sensibility is confined to the skin and responds to small differences in temperature, to light pressures, and gives tactile discrimination.

The sensory nerves provide separate fibers for the reception of stimuli of pain, heat, cold, light pressures, etc. The cutaneous

senses are distributed in a punctiform manner. Thus in appendicitis ordinary palpation gives rise to pain through a rather widespread stimulation of the nerve endings in the deep structures and of both the protopathic and the epicritic systems in the skin. Light stimulation of the skin, as by brushing with cotton or by gentle pinching, causes pain through the epicritic system alone—the stimulus being too delicate to affect the protopathic nerves. Pricking the skin with a pin affects the ending of an individual nerve fiber and causes either a protopathic or an epicritic pain. It is perfectly conceivable that there may be excessive excitability to a light brushing with cotton or to palpation and diminished excitability to the definitely localized stimulus of a pinprick. Sherren has corroborated and extended the work of Head as it applies to appendicitis. He writes: "In appendicitis cutaneous hyperalgesia varies from a complete band extending on the right side from the middle line below the umbilicus in front to the lumbar spines behind, down to a small circular spot a little above the middle point between the umbilicus and the anterior superior spine. This band corresponds to the eleventh dorsal area of Head. Very often the tenderness extends somewhat into the tenth dorsal area also and occasionally, but not often, into the twelfth dorsal area, sending a tongue-shaped process over the gluteal region." The usual area of hyperalgesia is triangular in shape and situated in the right iliac region. Occasionally the hyperalgesia is bilateral, it is never on the left side alone, and it does not vary with the site of the appendix.

Sherren, Moullin and others, particularly of the London Hospital School, consider disappearance of cutaneous hyperalgesia with persistence of the other symptoms of appendicitis to be significant of gangrene or perforation. Metzger found that hypoesthesia to a pinprick is rarely absent in the preceeal region during appendicitis, and argued that the abdominal reflex being dependent on the perceptive sensibility of the pain nerves, any decrease in their sensitiveness must lead to diminution or loss of that reflex. Whether Metzger's argument is correct or not there is no doubt as to the frequent presence of hypoesthesia to pinprick and the absence of the abdominal reflex. The presence of superficial hyperalgesia to gentle stroking is often a really valuable symptom in appendicitis.

Just as radiating impulses can stimulate sensory nerves so also may they affect motor nerves, and we have rigidity of muscles in the abdominal walls. The stimulation of any individual bundle of nerve fibers as it leaves the cord to go to one of the flat abdominal muscles causes contraction of the individual muscle fibers supplied by it and not of the whole muscle. The muscular contraction which results from a visceral stimulus may remain for an indefinite period and cause a tumor-like swelling. In cases of appendicitis where the examiner believes that he can palpate the appendix it is usually such contracted muscular fibers which he feels, and as there is also

present hyperalgesia of the muscle, the patient complains of pain and thus tenderness of the vermiform appendix is erroneously believed to be present.

Undoubtedly many of the so-called phantom tumors of the abdomen have an origin similar to the above

Mackenzie and his disciples believe that the abdominal sympathetic nerve centers are incapable of the perception of pain and that all visceral pain is of the nature of a viscerosensory reflex as described in the preceding paragraphs. This doctrine is very satisfactory in explaining many otherwise obscure symptoms, but it seems to ignore many important facts.

Mackenzie speaks of the pains due to increased peristalsis of the small intestine as being median and umbilical or epigastric; of the large intestine as being median but lower in site; of the stomach as being median and high in the epigastrium. The viscerosensory theory is a soul-satisfying explanation of the late pains in visceral disease, *e. g.*, at McBurney's point in appendicitis, but it fails utterly to explain the early median pains common to appendicitis, intestinal colic, etc. What reasonable explanation can be given for the median site of these pains and for the undoubted fact that the pains due to cholecystitis, to gastric and duodenal lesions, and to appendicitis may each closely or exactly simulate one of the others?

Several explanations may be given, each of which is open to criticism. Probably the truth may be found in some combination or modification of these explanations.

While the stimuli from a normal vermiform appendix can pass through the solar plexus to their proper center in the spinal cord, the greatly increased stream of stimuli from an inflamed appendix fails to be accommodated by the normal passageway through the plexus, and thus being prevented from free passage gives rise to a general solar-plexus disturbance. The most common cause of a general solar-plexus disturbance is the presence of some irritating substance in the stomach and small intestine, and the customary motor response is an endeavor to get rid of the irritant by increased peristalsis. The increased peristalsis is accompanied by pyloric spasm, hence vomiting. The pain of increased peristalsis is median and high up. Opinions differ much as to the power of the receptors of the gastro-intestinal nerves to appreciate pain. It is undoubtedly true that we can operate upon and can even maltreat exposed viscera without inflicting pain as long as we do not drag upon their mesenteries, but this does not prove that these receptors are incapable of translating certain types of stimuli into terms of pain.

Hertz believes that the abdominal viscera are exquisitely sensitive to deep pressure stimuli such as those produced by tension. Thus, slight distention of a gut leads to discomfort and marked stretching to severe pain. "The normal stimuli reactions in the intestine are those of contraction and relaxation; these two are

going on continuously. There is, as Meltzer has pointed out, a law of contrary innervation which permits of this wave of contraction and relaxation, and any interference with this law, such as occurs in colic, in obstruction, etc., gives rise to paroxysmal and severe pain. In colic an abnormally strong peristaltic wave occurs in one part of the alimentary canal, the part immediately below which should normally relax, following the law of contrary innervation, is unable to do so, owing to organic disease, or to spasm; the intermediary segment is thus subjected to steadily increasing pressure, which soon produces pain, the distention being an adequate stimulus." (Behan, Pain.) It is difficult to believe that these views of Hertz, Meltzer and others are not correct. As already noted the gastro-intestinal tract, the biliary apparatus, the pancreas, and the spleen are developmentally midline structures, their ultimate anatomical positions being merely due to the exigencies of storage space in the abdomen. The vascular and nerve supply of these structures must correspond with their developmental peculiarities and is essentially midline no matter how much the nerve fibers have been elongated to suit the acquired positions of the viscera. This being so it follows that pain such as may be produced by increased peristalsis must be primarily referred to the midline of the body. Of course after the stimuli have acted long enough or violently enough to produce centers of radiation, *i. e.*, to give rise to viscerosensory reflex phenomena, then the secondary or later pains may appear. One must not ignore the distribution of fibers of the right phrenic nerve to the anterior parietal peritoneum as low down as the umbilicus and their connection with the solar plexus through the phrenic ganglion, etc. A general disturbance of the solar plexus gives rise to certain symptoms common to many affections. A blow on the pit of the stomach may occasion nausea, vomiting, and colicky pains besides shock. Emotion, acting probably through the vagi, may cause nausea, vomiting, and colic. Acute cholecystitis may begin with a sensation of hunger followed by epigastric pain, nausea, and vomiting. All these symptoms are merely evidences of a general solar-plexus disturbance.

Confusion of symptoms may also arise by the intermediation of an axon reflex. "Every sympathetic ganglion is connected with the central nervous system, brain and cord, by efferent spinal fibers, preganglionic fibers, which terminate by arborization around the dendrites of the sympathetic cells. The efferent fibers arising from the latter may be designated postganglionic fibers." Langley and Anderson "give reasons to believe that any one preganglionic fiber may connect by collaterals with several sympathetic cells." (Howell.)

"The preganglionic fibers from which collaterals arise proceed *past* the sympathetic ganglion to arborize around nerve cells located peripherally, *i. e.*, in some viscus. When this viscus is inflamed, etc., an impulse travels (antidromically) up to the cell, thence to

another preganglionic fiber and therefore to ganglionic cells whose axons (postganglionic) are distributed to other viscera. By the disturbances which these impulses thus bring about (local spasms, vascular disturbances) afferent stimuli are set up which proceed to the nerve centers, but the viscus thus affected by the axon reflex may be far removed from that which is the seat of disease." (J. J. MacLeod.)

The complexity of the nerve connections of the viscera, the perfection attained in the fulfilment of their vegetative or automatic functions, and the rarity of the higher centers being given cognizance of what is going on in the digestive tract, apart from a feeling of well being or satisfaction, excuse if they do not explain the confusion in the differential diagnosis of such distinct anatomic entities as appendicitis, pancreatitis, cholecystitis, gastric and duodenal ulcers.

The referred pains of which we have been speaking may be closely simulated by other very important pains. Inflammation extending from the organ primarily involved may of course come into a region supplied by spinal nerves and thus pain result, such as the lumbar pain experienced in cases of retrocecal appendicitis, or the inflammation may spread to another organ adherent to that primarily involved, and thus a secondary referred pain may be noted. An example of this latter condition is where an inflamed appendix becomes adherent to the prostate and gives rise to pain at the point of the penis. In appendicitis pain may be experienced on the left side of the abdomen through direct extension of peritonitis or possibly, in the absence of such extension, by *allochiria*, because, according to Head and Howell, "when from any cause one or other of the cutaneous senses is depressed in a given area stimulation in this region may give sensations which are referred to a symmetrical area on the opposite side of the body."

The nerve supply of the renal pelvis and ureter comes through the inferior mesenteric, spermatic, and hypogastric plexuses, and, according to Head, their central connections are through the tenth, eleventh, and twelfth dorsal and first lumbar nerves.

Unlike the gastro-intestinal canal the kidneys and ureters are paired organs—they are not of midline origin. Pain in the renal pelvis and ureter seems to be excited principally by vigorous contractions of their unstriped muscular fibers; is of the viscero-sensory reflex type, and is referred to the area of distribution of the eleventh dorsal to the first or second lumbar. Thus the pain in renal colic begins in the back above the crest of the ilium, passes around in front, and slants down to the testicle. The peculiar course of the pain does not give much information regarding the site of the stone. A stone situated low down in the ureter may cause contractions of the ureteral musculature beginning at the renal pelvis and passing downward—these give rise to the classical pain as described above. In a man of thirty-four years who suffered many attacks of severe pain situated at or below McBurney's point with localized

tenderness, rigidity, and fulness, but without any pain in the epigastrium or umbilicus and without any true nausea, there was pain in the right testicle, but there was no fever. Urinary examination showing blood shadows, a Roentgen-ray examination was made which showed a calculus in the pelvis of the kidney well above any point where pain or tenderness had been experienced. In this case no wave of peristalsis was likely to pass down the ureter. Pressure and percussion over the kidney elicited no symptoms, but pressure over the sensitized abdominal wall near McBurney's point did evoke pain distant from the focus of irritation in the renal pelvis. Mackenzie considers that when attacks of renal colic always begin with pain at one definite spot, no matter how that pain may radiate it is very strong evidence that the calculus is remaining fixed in one position. Should the calculus move downward it is probable that the impulses passing up through the sympathetic will reach lower cord segments, and radiating there will affect nerves with different peripheral distribution.

In some cases of renal colic symptoms of intestinal obstruction may lead to error in diagnosis. These symptoms may perhaps be explained by a consideration of the nerve supply of the anal region. The sympathetic supply to the rectum comes from the inferior mesenteric and the upper and lower divisions of the hypogastric plexuses, while the cerebrospinal supply comes through the second, third, and fourth sacral nerves. "It has been shown by experiments on animals that the cerebrospinal nerves (from the second, third, and fourth sacral) convey motor impulses to the longitudinal fibers but inhibitory impulses to the circular muscular fibers. In like manner the branches from the sympathetic convey motor fibers (derived from some of the lumbar rami communicantes) to the circular muscle, and inhibitory to the longitudinal muscle of the rectum. The reflex centre which governs the action of the sphincters and the muscular fibers of the rectum ("defecation centre") is situated in the lumbar region of the cord." (Cunningham.)

From this it appears possible that impulses passing up from the ureter to the aortic plexuses may produce a disturbance there, sufficient to cause the transmission of motor impulses through the hypogastric plexus to the rectal sphincters and thus set up a tonic contraction. Such tonic contraction is present in the cases where renal colic is mistaken for obstruction.

The urinary bladder is developmentally a midline organ and the pains which result from its irritation are also midline. The nerve supply is from the sympathetic and comes from the upper lumbar region and from the sacral autonomic (second and third sacral). Thus sensory symptoms appear in two regions, viz., in the area of distribution (1) of the upper lumbar nerves, *i. e.*, in the hypogastrium and (2) of some of the sacral nerves, *i. e.*, in the perineum and penis. As the nerve supply of the bladder and of the rectum is in some respects similar it is no wonder that a

patient sometimes is in doubt as to whether certain pelvic sensations are a call for urination or defecation, or for both.

The nerve supply of the prostate and seminal vesicles is derived from the hypogastric plexus. When these organs are the seat of inflammation, especially of a chronic variety, there may be few if any symptoms drawing attention to them. The impulses passing up through the hypogastric plexus may radiate to such an extent that much confusion may result. Hugh Young[1] writes: "The nervous symptoms are often so remote and disconnected that the prostate is not suspected. I have seen many cases of lumbago, sciatica, vague pains in the back, hips, thighs, perineum, groin, and often as far as the soles of the feet, caused by chronic inflammations of the prostate and seminal vesicles which by involving nerve terminals cause stimuli to be sent to the spinal cord and there transmitted to other visceral and superficial regions according to the dicta laid down by Head in his explanation of the etiology of referred pains. I hope that I may be pardoned for digressing somewhat to call attention thus to the great importance of examining the prostate in many painful conditions anywhere between the diaphragm and toes when there are no localizing symptoms to direct attention to the prostate itself. In such cases it is often the site of an extensive chronic inflammatory process which is the cause of the whole trouble. I know of ten cases in which there was operation for renal calculus, the symptoms of which were typical; severe intermittent colicky pain radiating to the groin and associated with symptoms of hematuria and entirely due to a chronic inflammatory process in the prostate and seminal vesicles with reflex referred pains to the kidney region, the blood coming from a congested and inflamed posterior urethra." When one makes a rectal examination in a patient suffering from a number of rather obscure pains and finds exquisite tenderness of the prostate and vesicles, and especially if pressure on the vesicles causes a flow of pus into the urethra, one is very strongly inclined to believe that he has discovered the *fons et origo mali*. It is necessary to remember, however, that in the case of prostatitis and vesiculitis the more or less distant pains may be due to the action of toxins and not to radiation of impulses through the sympathetic.

The object of this paper has been to endeavor to systematize some of our common knowledge and some of our common theories regarding the incidence and distribution of pain produced by disease affecting the abdominal organs supplied by the sympathetic nervous system. In his own work the author has found this rather crude systematization useful and hopes that it may also be of service to others.

[1] Jour. Am. Med. Assn., September 13, 1913.